LADWP Fuel Cell Demonstration Project

250 kW - Molten Carbonate Fuel Cell Power Plant
Located at
John Ferraro Building, Los Angeles

Final Report

Reporting period: August 2001 – August 2002

September 12, 2003

DOE Award Number: DE-FG26-00NT40962

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Disclaimer

Abstract:

LADWP is currently one of the most active power utility companies in researching fuel cell technology. Fuel cells offer many benefits and are now used as an alternative to traditional internal combustion engines in power generation. In continuing it's role as the leader in fuel cell research, LADWP has installed a pre-commercial molten carbonate fuel cell on August 2001 at its headquarter, the John Ferraro Building. The goal of this project is to learn more about the actual behavior of the fuel cell running under real world conditions. The fuel cell ran smoothly through the first year of operation with very high efficiency, but with some minor setbacks. The JFB fuel cell project is funded by the City of Los Angeles Department of Water and Power with partial grant funding from the Department of Defense's Climate Change Fuel Cell Buydown Program. The technical evaluation and the benefit-cost evaluation of the JFB fuel cell are both examined in this report.

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Executive Summary:

The Los Angeles Department of Water and Power (LADWP) is a municipal electrical power company that has been delivering quality power to the City of Los Angeles for more than 100 years. Today LADWP provides power to more than 1.5 million of its' commercial and residential customers. The John Ferraro Building located in Downtown Los Angeles, California, is LADWP's headquarters. Being a large facility, the JFB operates at a load of more than 5 MW. The fuel cell project for the JFB consists of 3 phases. The first phase involved installing a grid-connected 250 kW fuel cell at the JFB site where it would be monitored continuously for one year. The second phase will involve heat recovery from the plant where the heat would be used as heating at the JFB. For the final phase, the fuel cell would operate in a load-connected operation. As of now, LADWP has successfully completed phase 1 of the project.

A 250 kW molten-carbonated fuel cell (MCFC) made by FuelCell Energy was installed at Los Angeles Department of Water and Power's (LADWP) headquarters, the John Ferraro Building in August of 2001. This fuel cell helps supply an additional 250 kW of power into LADWP's grid. A more significant reason for the installation of this fuel cell is to demonstrate fuel cell application and reliability under real world operating conditions. The fuel cell demonstration project would further advance FC technology by using independent performance test data over an extended period.

The total capital allocated for this project is approximately $3.2 million. The funding is made possible by LADWP's own budget and federal funding program from U.S Department of Defense Climate Change Buydown Program, administered by DOE. The JFB fuel cell accumulated more than 5,000 hours of operation during it's one year of service reaching an availability of more than 60%. The total energy output for the first year is more than 900MWh. The JFB fuel cell plant only had two major forced shutdowns during the one-year operation. Both shutdowns were due to damaged fuel cell stack modules where replacements were needed from Fuel Cell Energy (FCE).

The thermal heat recovered from the fuel cell power plant will be used in the heating system of the JFB's for the phase 2 of this project. This cogeneration feature of high temperature fuel cell makes the efficiency even higher compared to other generation technologies. As expected, the total NOx and SOx emission were virtually zero with NOx being less than .1 part per million and SOx being less than .01 part per million. These emission results further prove the environmental benefits of a fuel cell.

The benefit to cost analysis shows the installation of a fuel cell to be not economically feasible because of the high initial cost of the plant. Forecasters predict with continuous growth in fuel cell application in the commercial sector, the cost will be driven down to $1000/kW. For mass production of fuel cells to become a reality, fuel cell stability and efficiency must be improved upon. The fuel cell at the JFB was one of only two plants in operation in the U.S. where the field trials have yielded valuable information for the commercial plant design.

This fuel cell project further proves that fuel cells are a very reliable and efficient form of power generation. Fuel cell technology has virtually zero NOx and SOx emissions, which makes fuel cell an environmentally friendly form of power generation. The achievement of this project contributed to the evaluation of fuel cell technology, providing technical and commercial data that will be valuable for further fuel cell technology development.

Introduction:

Today, LADWP delivers power to more than 1.5 million commercial and residential customers. Being one of the leaders in the power generation industry, LADWP continuously strides to find a cleaner and more efficient method of power generation. With fuel cell being one of the cleanest and most efficient power generating technology today, LADWP plans to establish its position as a pioneer in fuel cell power generation by installing one of the world's first large scale, pre-commercial molten-carbonated fuel cell unit at it's headquarter at the John Ferraro Building. The power generated from this fuel cell unit goes into LADWP's power grid and the heat recovered will be used for heating/cooling purposes at the JFB in the phase-2 operation.

The fuel cell manufacturer LADWP selected to supply the fuel cell was FuelCell Energy based in Danbury, Connecticut. FuelCell Energy was selected as a supplier for this project because of their expertise and experience in fuel cell research and development. After consulting with FuelCell Energy, the fuel cell model selected was the DFC 300A, which delivers a maximum output of 250 kW.

The primary objective of this project is to collect valuable field data through the one-year of operation. This field data would be used by FuelCell Energy to develop a more reliable fuel cell unit in the near future. The field data will also provide valuable technical data and experience for future fuel cell projects by LADWP.

Results and Discussion

The following paragraphs provide details about the first Year of operation of the fuel cell power plant at the JFB in Los Angeles. They focus on power plant reliability, costs and expenses, efficiency and on operation and maintenance issues. The following table lists the specifications of the fuel cell.

Installation

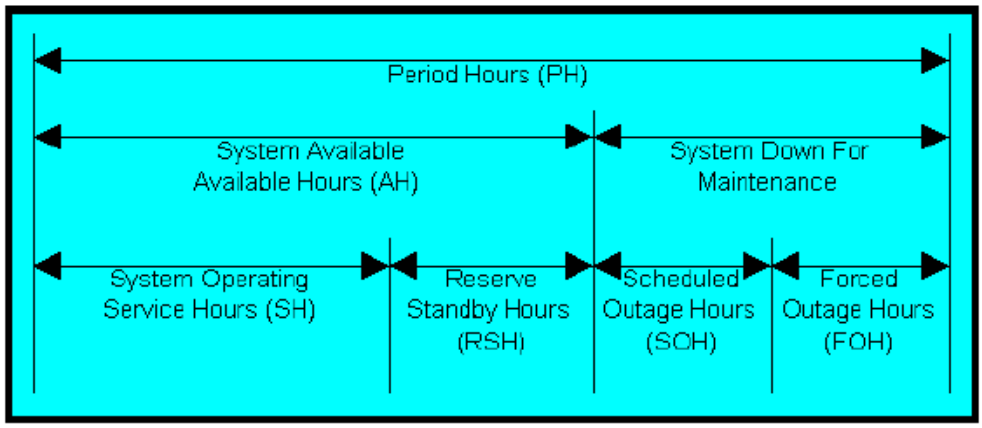
The project implementation began with a signed contract, which authorized expenditures of up to $2.4 million by LADWP. The contract led to the purchase of the unit on June 2, 2000. The purchase involved a 250 kW molten carbonate Fuel Cell model DFC 300A manufactured by Fuel Cell Energy, capable to operate independent of the utility grid. The power plant was received on site on August 4, 2001. The delivery was a very smooth process with no problem encountered.

Commissioning

The DFC 300A Fuel Cell power plant was commissioned on August 8, 2001, and the first start-up successfully took place on August 10, 2001.

Reliability Analysis (MTBF)

To determine the reliability statistics, performance indices are used that are published by the Gas Technology institute (GTI) in Des Plaines, Illionois.



Reliability Performance Indices	Formula
Period of Demand (POD): *Measures the time the unit was planned to operate.*	$POD = PH - RSH - SOH$
Availability Factor (AF, %): *Measures, on a percent basis, the unit's "could run" capability. Impacted by planned and unplanned maintenance.*	$AF = \frac{(PH - SOH - FOH) \times 100}{PH}$
Forced Outage Rate (FOR, %): *Measures portion of downtime due to unplanned factors.*	$FOR = \frac{FOH \times 100}{SH + FOH}$
Scheduled Outage Factor (SOF, %): *Measures percent of time set aside for planned maintenance.*	$SOF = \frac{SOH \times 100}{PH}$
Service Factor (SF, %): *Percent of total period hours the unit is on-line – varies due to site-related or economic factors.*	$SF = \frac{SH \times 100}{PH}$
Mean Time Between Forced Outages (MTBFO): *Measures the nominal time between unscheduled forced outages.*	$MTBFO = \frac{SH}{\#\ ForcedOutages}$
Mean Down Time (MDT): *Measures the nominal duration the unit is down during maintenance events.*	$MDT = \frac{SOH + FOH}{\#\ ForcedOutages + \#\ PlannedOutages}$

(Source: http://www.gri.org/pub/solutions/dg/rel_metrics.html)

Reliability Performance Indices	
Period Hours, PH	8,760 hrs
Scheduled Outage Hours, SOH	3,114 hrs
Forced Outage Hours, FOH	85 hrs
Reserve Standby Hours, RSH	0 hrs
System Available – Available Hours, AH	5,561 hrs
System Operating Service Hours, SH	5,561 hrs
Period of Demand, POD	5,646 hrs
Availability Factor, AF	63.5 %
Forced Outage Rate, FOR	0.9 %
Scheduled Outage Factor, SOF	35.5 %
Service Factor, SF	63.5 %
Mean Down Time, MDT	213.3 hrs
Mean Time Between Failure (MTBF)	794.4 hrs
System Total Output (kWh)	914,665 kWh
System Peak Output (kW)	233 kW

Total Fuel Cell Plant Capacity (kW)	250 kW
Heat Rate Ave Yr (BTU/kWh)	8,060 BTU/kWh
Heat Rate Including Hot Stand By (BTU/kWh)*	8,200 BTU/kWh
Capacity Factor (% of Nameplate Rating)	41.8%
Thermal Output (Btu/yr), if byproduct used	N/A

*Hot Stand By is a state where the Fuel Cell consumes fuel without producing electricity to maintain a certain temperature to prevent Fuel Cell damage. The Fuel Cell had over 50 days of Hot Stand By during the year.

Shutdown Summary:

The DFC 300A model fuel cell was delivered to the JFB on August 4, 2001 and installed by FuelCell Energy. On August 10, 2001 the fuel cell began producing net power to the grid, which marked the beginning of the one-year running period. The plant continued to operate normally for a month but then in mid-September, 2001 the performance of the plant's Fuel Cell Module started to decay due to manifold leak within the fuel cell stacks. The fuel cell plant was shut down on October 18, 2001 due to internal deterioration of the fuel cell and on October 27, 2001 the fuel cell stack module was returned to the factory for inspections. A new fuel cell stack was installed on January 26, 2002 and testing resumed on February 21, 2002.

During it's first year of operation, the fuel cell plant provided more than 900 MWhrs net AC to the grid. To insure proper maintenance, the fuel cell plant was monitored by FCE in Danbury, Connecticut through a secure data line throughout the one-year of operation. The following table shows a detailed timeline of the shutdowns at the JFB fuel cell.

Description/Event	Date and Time	Loadtime	Run Hours	System Down Hours
First Start-up	8/10/2001 8:12am	144		
Temporary shutdown to Hot Standby while replacing software in the DC-AC inverter communications module.	8/10/2001 7:43pm	156	12	
Restart	8/10/2001 10:43pm	156		3
Temporary shutdown to Hot Standby while replacing an air blower control module.	8/18/2001 11:42am	337	181	
Restart	8/18/2001 2:40pm	337		3
Temporary shutdown to Hot Standby while replacing a pressure instrument's o-ring seals.	8/23/2001 8:08am	450	113	
Restart	8/23/2001 10:00am	450		2
Shutdown to ambient due inspections and improvement modifications of the humidifier / heat-exchanger module.	9/8/2001 5:36pm	842	392	
Restart	9/13/2001 11:32am	842		114

Description/Event	Date and Time	Loadtime	Run Hours	System Down Hours
Shutdown to ambient due to internal deterioration of the fuel cell module. A new module needs to be manufactured, delivered and installed.	10/18/2001 3:45pm	1686	844	
Restart with new fuel cell module and humidifier / heat-exchanger modules.	2/3/2002 10:15pm	1686		2599
Plant trip due to a malfunctioning gas detector.	2/4/2002 12:50pm	1700	14	
Restart	2/4/2002 4:45pm	1700		4
Shutdown to ambient temperature to fix control-wiring's hot-seals at module penetration.	2/13/2002 8:40am	1908	208	
Restart	2/19/2002 6:00pm	1908		153
Plant trip due to the DC-AC inverter's electronics card failure and replacement.	3/8/2002 7:30pm	2318	410	
Restart	3/9/2002 9:00pm	2318		25
Plant trip due to operating error.	3/10/2002 2:00am	2323	5	
Restart	3/10/2002 8:00am	2323		6
Plant trip due to leak in the humidifier / heat exchanger external welding.	3/20/2002 2:00pm	2569	246	
Restart	3/21/2002 2:00pm	2569		24
Plant trip due to operating error.	4/1/2002 12:00pm	2831	262	
Restart	4/1/2002 1:00pm	2831		1
Plan trip on water treatment system high storage tank level.	4/6/2003 5:00pm	2955	124	

Description/Event	Date and Time	Loadtime	Run Hours	System Down Hours
Restart (during level switch adjustments a PVC pipe broke)	4/7/2002 8:00am	2955		15
Plant shutdown in order to replacing the humidifier / heat exchanger with a new design.	5/10/2002 12:00pm	3751	796	
Restart	5/12/2002 12:00pm	3751		48
Shutdown due to a mishap occurred with a new humidifier/heat exchanger that sent excess steam into the fuel cell module.	6/12/2002 5:51pm	4501	750	
Restart	6/13/2002 3:41am	4501		10
Shutdown to ambient temperature to assess plant damages caused by prior shutdown incident.	7/26/2002 2:00pm	5543	1042	
Restart, install new stack module	8/3/2002 2:00pm	5543		192
End of one year Operation.	8/10/2003	5705	162	

Emissions

The LADWP constantly strives to improve the air quality in the city of Los Angeles. By installing a 250 kW molten-carbonated fuel cell (MCFC), LADWP is reducing the amount of harmful chemicals in the air such as NOx or CO. From this table, it can be seen that the amount of NOx produced is negligible along with the other harmful chemicals.

Emissions	JFB Fuel Cell Emissions (15% O_2)
NOx	0.0004 lb/MWh
SOx	0.003 lb/MWh
VOC	<10 ppmv
CO	<10 ppmv
Particulates	Negligible
Smoke	None

Thermal Output

Fuel cells are very clean forms of producing power and the main byproduct is water and heat. The heat from the fuel cell can be used for heating purposes or for cooling purposes using absorption chillers. The utilization of heat recovery can increase the efficiency of the fuel cell from 35-40% to 80-85%. Currently the fuel cell at the John Ferraro Building (JFB) is in phase-1 of its operation where the power generated from this fuel cell unit goes into LADWP's power grid. Phase-2 of the operation is to recover heat from the fuel cell for use at the JFB.

Cost Parameter

The following table provides the economic data from the first year of operation.

Specification	Data
Total Fuel Cell Plant Cost ($)	$2,400,000
Fixed Operating Cost	10 mills/kWh
Variable Operating Costs (mil/kWh)	39 mills/kWh
Local Area Electricity Price (cents/kWh)	5 cents/kWh for generation 9 cents/kWh for delivered
*Fuel Price ($/MBtu)	$4.85/MBTU

*Year Average from August 2001 to August 2002

Cost-Benefit Evaluation

Activity	Cost
Investment	
Total Fuel Cell Plant Cost	$2,400,000
Installation Cost	$800,000
Total Investment	**$3,200,000**
Funding	
U.S. DOE	$250,000
Total Funding	**$250,000**
Total Costs	
Fuel Cost	$36,370
Operation and Maintenance Cost	$50,400
Total Costs	**$86,770**

Electrical Consumption of John Ferraro Building (JFB)

JFB Prior to Installation

Date	Electrical Use (kWh)	Peak Electrical Use (kW)
Aug-00	4,252,800	8,371.2
Sep-00	3,998,400	8,390.4
Oct-00	3,729,600	7,833.6
Nov-00	4,512,000	7,449.6
Dec-00	3,696,000	7,296.0
Jan-01	3,796,800	7,219.3
Feb-01	3,220,800	7,411.2
Mar-01	3,681,600	7,353.6
Apr-01	3,240,000	7,238.4
May-01	3,993,600	7,468.8
Jun-01	3,571,200	7,872.0
Jul-01	4,209,600	7,833.6
Aug-01	3,576,000	7,622.4

JFB During Operation

Date	Electrical Use (kWh)	Peak Electrical Use (kW)
Aug-01	3,576,000	7,622.4
Sep-01	3,700,800	7,334.4
Oct-01	3,705,600	7,603.2
Nov-01	4,180,800	7,507.2
Dec-01	3,796,800	7,084.8
Jan-02	3,355,200	6,988.8
Feb-02	3,340,800	7,468.8
Mar-02	3,643,200	7,008.0
Apr-02	3,398,400	6,950.4
May-02	3,556,800	7,651.2
Jun-02	3,451,200	7,353.6
Jul-02	4,123,200	7,776.0
Aug-02	3,590,400	7,536.0

The 250kW molten carbonate fuel cell is connected directly to LADWP's power grid system which helps supply an additional 250 kW. Since the fuel cell is connected to the power grid instead of the John Ferraro Building, the electric consumption of the JFB site will not be affected.

Fuel Consumption of John Ferraro Building (JFB)

JFB Prior to Installation

Date	Gas Use (MMBtu)	Peak Gas Use (MMBtu/dy)
Aug-00	0	0.0
Sep-00	0	0.0
Oct-00	0	0.0
Nov-00	0	0.0
Dec-00	0	0.0
Jan-01	0	0.0
Feb-01	0	0.0
Mar-01	0	0.0
Apr-01	0	0.0
May-01	0	0.0
Jun-01	0	0.0
Jul-01	0	0.0

JFB During Operation

Date	Gas Use (MMBtu)	Peak Gas Use (MMBtu/dy)
Aug-01	1,383	76.9
Sep-01	721	76.9
Oct-01	884	58.5
Nov-01	504	36.3
Dec-01	513	36.3
Jan-02	390	36.3
Feb-02	1,825	77.1
Mar-02	1,756	76.9
Apr-02	2,349	77.1
May-02	2,210	77.1
Jun-02	2,241	76.9
Jul-02	2,081	74.3
Aug-02	1,779	76.3

Prior to the installation of the 250kW molten carbonate fuel cell; the John Ferraro Building did not have any gas service. The fuel cell was installed along with two 30kW

Capstone microturbines and a 60kW Capstone microturbine. The fuel cell was not in operation during November 2001 to January 2002 due to internal deterioration of the fuel cell but the site still consumed fuel to operate the three microturbines, therefore the data of fuel consumed at John Ferraro Building, as shown above, is shared among one fuel cell and three microturbines.

Fuel Cell Electric Output

Date	Electric Output (kWh)	Peak Electric Output (kW)
Aug-01	108,900	232.1
Sep-01	76,299	232.0
Oct-01	42,876	126.8
Nov-01	0	0
Dec-01	0	0
Jan-02	0	0
Feb-02	53,964	233.1
Mar-02	153,239	231.6
Apr-02	136,078	233.0
May-02	99,982	232.8
Jun-02	127,833	231.6
Jul-02	115,494	216.7
Aug-02	0	0
Total	914,665	

The 250kW molten carbonate fuel cell produced a total of 915MWh within its first year of operation. The fuel cell performed well its first year and helped relieve the LADWP power grid. There was no power output during the month of November 2001 to January 2002 due to internal deterioration of the fuel cell. This required the installation of a new fuel cell stack that was installed in February 2002.

Conclusion

The DFC 300A fuel cell power plant at the John Ferraro Building (JFB) in Los Angeles, California successfully completed its first year of operation. The DFC 300A supplied a total of 915MWh into the Los Angeles Department of Water and Power (LADWP) Grid. Along with the power supplied to the LADWP grid, the DFC 300A also provided valuable technical and real world data, which will help for future fuel cell installation.

The Los Angeles Department of Water and Power took the initiative to lead the charge in fuel cell research by being the first company to install and operate a commercial high temperature fuel cell. By leading the charge in fuel cell research, LADWP strives to commercialize fuel cells to drop the high equipment costs of fuel cells. Fuel cells are highly efficient and environmentally friendly but due to the high costs of fuel cells many companies are hesitant of purchasing fuel cells. Along with the purchase of the DFC 300A at the JFB, LADWP also purchase three more fuel cells for other LADWP sites, which will help promote fuel cell technology. On March 2003, LADWP held a dedication ceremony at the JFB promoting the DFC 300A, where the media came to ask and learn more about fuel cell technology.

With the purchase of the DFC 300A, LADWP is not only providing electricity to the grid but is also cleaning up the air in Los Angeles. Fuel cell power plants are a highly efficient source of energy where its main byproduct is heat and water. Fuel cell can also reuse the heat from the fuel cell and reach an efficiency of 80% or higher. By using fuel cell power plants to generate power, LADWP is able to reduce the amount of harmful pollutants in the air such as NOx and SOx.

With the help of the Department of Energy to help fund the purchase of fuel cells, LADWP will be able to promote and eventually reduce the equipment costs of fuel cells allowing more companies to utilize this clean and efficient technology.

Photo Gallery

Site Preparation

Delivery of Fuel Cell

Connecting the Fuel Cell

Fuel Cell Operating

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